Tuning in to anxiety-related differences in attentional control: Apprehension of threat improves template switching during visual search

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ABSTRACT

Anxiety is believed to disrupt selective attention, supported by evidence that both individual differences in trait anxious personality and induced apprehensive mood can increase distractibility during visual search. While much research has focused on the role of anxiety-related emotion in affecting the ability to 'tune-out' irrelevant information, there is a scarcity of research on its possible role in affecting the 'tuning-in' of attention to relevant information. Here, we examined the role of both trait anxiety and induced apprehension on the efficiency to maintain one or more target templates to guide attentional selection during visual search, and the switch between search templates. In different blocks, participants searched for target objects defined by a single constant color (one-color-search), or by one of two possible colors (two-color search). Trait anxiety was measured by self-report questionnaire, and apprehensive mood was induced in a subset of 'threat' blocks, where loud aversive noise was occasionally presented. Relative to 'safe' blocks, search RTs were generally faster in 'threat' blocks. Crucially, induced apprehension also reduced target color switch costs during two-color search. No relationship between trait anxiety and performance was observed. These results show that acute apprehension can affect 'tuning in' functions of attentional control, by paradoxically improving the efficiency of switching target templates during visual search. Influences of trait anxious personality may be mainly confined to 'tuning out' processes of attention.

Keywords: Anxiety, Threat, Attentional control, Visual search, Task switching

INTRODUCTION

The experience of anxiety and stress can elicit a number of changes in cognitive function (e.g., Arnstein, 2009; Bishop, 2007). One of these is attentional control, which is often conceptualized as including the three core function of inhibition, task switching, and the updating of task representations within working memory (Miyake et al., 2000). Cognitive models such as the Attentional Control Theory (Eysenck, Derakshan, Santos, & Calvo, 2007) propose that that high levels of trait or current anxiety can impair these three functions. Such impairments have been well documented for inhibitory “tuning out” aspects of attentional control (i.e., the ability to suppress and ignore task-irrelevant information; see Derakshan & Eysenck, 2011; Berggren & Derakshan, 2013a, for reviews). Individuals characterized by high levels of trait anxious personality show deficits in their ability to ignore distractions (e.g., Berggren & Derakshan, 2013b; 2014; Moser et al., 2012; Pacheco-Unguetti, Acosta, Callejas, & Lupiáñez, 2010). Similar findings can also be observed as a result of inducing an anxious or apprehensive mood, achieved through techniques such as threat of aversive stimulation during selective attention tests (e.g., Choi, Padmala, & Pessoa, 2012; Gutierrez & Berggren, 2020), although there is also evidence that distractibility can be reduced under some conditions (e.g., Booth, 2018; see Gutierrez & Berggren, 2020, for further discussion).

In contrast, the hypothesis that anxiety may also affect “tuning in” aspects of attentional control that enable us to focus processing on task-relevant information has been studied less intensively. A few studies have employed task-switching procedures to show that high levels of trait anxiety impair the ability to re-allocate attention when task-relevant attributes change. For example, high levels of either trait or induced anxiety can increase errors within the Wisconsin

Card Sorting Task where participants are required to shift between rule-sets while sorting cards of images by attributes such as their color, shape, or numerosity (e.g., Casselli, Reiman, Hentz, Osborne, & Alexander, 2004; Edwards, Edwards, & Lyvers, 2015; Gershuny & Sher, 1995). In addition, larger switch costs in reaction times can be observed among high trait anxious participants when switching between location and arrow direction judgements (Gustavson, Altamirano, Johnson, Whisman, & Miyake, 2017). Furthermore, highly anxious individuals tend to show faster switches from an affectively neutral towards a threat-related task, but slower switches away from this task (Paulitzki, Risko, Oakman, & Stolz, 2008). Studies examining the effects of induced anxious/apprehensive mood manipulations on performance in switch tasks have produced mixed results. Kim, Lee, and Anderson (in press) employed a visual search task where participants chose to search through one of two color-defined stimulus sets, where searching the smaller set would optimize performance. Threat of a mild electric shock improved performance, specifically on trials where switching between colors was the optimal strategy, suggesting that induced apprehension can facilitate the ability to change attentional selection strategy. Other studies have examined how task switching is affected by longer-term stressful states such as apprehension over a future event like public speaking or feelings of anxiety around the time of academic examinations. While Plessow et al. (2012) found that heightened apprehension increased performance costs on switch trials, Kofman et al. (2006) found the opposite pattern, with reduced switch costs when apprehension levels were high.

The ability to switch between task sets is just one aspect of the “tuning in” functions of attentional control. Another aspect that might also be affected by anxiety is the ability to maintain one or more representations of currently task-relevant objects or events in working memory. Such ‘attentional templates’ are assumed to facilitate the selection of pre-defined target objects in visual search displays where they appear among multiple distractors at unpredictable locations, by guiding attention towards objects with template-matching features (Duncan & Humphreys, 1992; see also Eimer & Kiss, 2008; Folk, Remington, & Johnston, 1992). The question whether increased levels of trait anxiety or induced apprehensive mood might affect the ability to efficiently maintain and utilize attentional templates during visual search has not yet been systematically examined.

The goal of the current study was to investigate this general question in two different ways. On the one hand, we assessed the impact of trait anxiety and induced apprehension on the ability to maintain multiple attentional templates at the same time. On the other hand, we investigated whether and how trait anxiety and induced apprehension affect the efficiency of switching between attentional templates. To address these questions, we employed two types of visual search tasks with color-defined targets. In the one-color task, participants searched for a particular color target that remained constant throughout. In the two-color task, they searched for one of two possible color targets which appeared with equal probability and unpredictably in any given search display. To test the influence of anxiety on performance in these tasks, we measured both trait vulnerability to anxious personality using a self-report questionnaire, and the effect of induced apprehensive mood on performance. This was achieved by asking participants to complete both ‘safe’ and ‘threat’ blocks within each of the two tasks. In ‘threat’ blocks, short sound bursts could be presented on a small percentage of trials over headphones. Most of these sounds were high in both rated negative affect and physiological arousal, and were presented at loud volume, to induce apprehension throughout the threat blocks. The specific contributions of negative affect versus arousal on attentional control are generally difficult to disentangle. In a study where affectively positive or negative pictures were presented as spatial cues immediately prior to target stimuli (Vogt et al., 2008), spatial cueing effects were larger for highly arousing images regardless of their affective valence. This indicates that immediate attentional effects in response to affective stimuli may be primarily driven by induced arousal. To eliminate any such transient sound-induced effects in the present study, trials where a sound was presented and the subsequent trial were excluded from analyses. This procedure was similar to that of a recent investigation which demonstrated that induced apprehension can impair inhibitory control over salient task-irrelevant distractors (Gutierrez & Berggren, 2020; see also Moser et al., 2012, for similar results in relation to trait anxiety).

Previous studies have shown that reaction times (RTs) to targets are slower during two-color as compared to one-color search (e.g., Grubert & Eimer, 2013; Houtkamp & Roelfsema, 2009; Rushworth, Passingham, & Nobre, 2005). These two-color search costs are indicative of competitive interactions between multiple simultaneously active search templates. If either trait anxiety or induced apprehension affects the ability to efficiently maintain attentional templates, this should be reflected by impaired search performance, and more specifically by increased costs during two-color search, where the demands on attentional control are more pronounced. To investigate the effects of anxiety and apprehension on the ability to switch between search templates, we focused on the two-color search task, and compared stay trials where the target color was the same as on the immediately preceding trial and switch trials where the color of the target changed relative to the preceding trial. Previous studies have shown that RTs are slower on switch as compared to stay trials (e.g., Rushworth et al., 2005), and the question was whether trait anxiety or induced apprehension would modulate these template switch costs. If these factors impair the ability to flexibly control the activation states of multiple attentional templates during two-color search, this should result in larger switch costs. Given that previous studies focusing on induced apprehensive mood (Kim et al., in press; Kofman et al., 2006; Plessow et al., 2012) produced conflicting findings, with apprehension resulting in either reduced or increased switch costs, we again assessed these costs separately.

METHOD

Participants

Fifty participants were initially recruited to participate in the experiment. Of these, two participants were excluded and replaced with new participant data due to a high overall error rates in the task: one with accuracy at below chance-level and one with average error rates over 3 SDs from the rest of the sample. Of the final sample (*M* age = 26 years, SD = 6; 22 male; 4 left-handed), all reported normal or corrected-to-normal vision, normal color vision, and were naïve to the experimental hypotheses. All methods and procedures in the study were approved by the Psychology departmental ethics committee, Birkbeck University of London.

Desired sample size was informed by two prior experiments. A pilot study (N = 18) using similar methods to the current experiment provided an estimated effect size for a two-way within-subjects interaction involving Task Set and Noise Condition of *dz* = .53. Analysis using G*Power software (Faul, Erdfelder, Lang, & Buchner, 2007; Faul, Erdfelder, Buchner, & Lang,

2009) gave a recommended sample size of 30 participants, assuming an alpha level of .05 and power of .80. For trait anxiety, we used the r-value correlation associated with increased attentional capture by color singletons during visual search observed in high anxious individuals (r = .43; Moser et al., 2012), which produced a recommended sample size of N = 40 using the same criteria. We set our desired sample size to N = 50, which is sufficiently powered to detect an association with trait anxiety of ~ r = .40 or greater.

Stimuli and Procedures

The experimental task was programmed and executed using E-Prime 2.0 software (Psychology Software Tools, Inc.). Stimuli were shown on a 19-inch monitor (60 Hz; 1280 x 1024 screen resolution) at a viewing distance of ~ 60 cm. Responses were recorded via standard keyboard button presses. Stimuli were presented on a black background, with a gray fixation dot (0.10 x 0.10 degrees of visual angle) presented constantly throughout blocks. On each trial, a search display consisted of six colored rectangular bars (2.29 x 1.15°), positioned at six equidistant locations from fixation, at an eccentricity of 4.49° measured from the center of each object. Two of these bars were located on the horizontal midline to the left and right of fixation. Each display always contained three horizontally oriented and three vertically oriented bars, which were randomly allocated to possible positions, though the orientation and position of the target object was counterbalanced. The colors used in the experiment were red (CIE coordinates: .587/.320), blue (.205/.204), green (.283/.573), magenta (.281/.190), yellow (.442/.471), orange (.578/.383), and gray (.329/.354). Blue and green served as the target colors for all participants. All colors were equated for luminance (35 cd/m^2). The choice of blue and green as target colors was motivated by the goal to make these two colors clearly distinct from each other under conditions of equiluminance, while at the same time avoiding red as possible target colors (as red may be associated with avoidance motivation, which could interact with trait anxiety or induced apprehension; e.g., Elliot & Maier, 2007).

Noise stimuli were 23 possible sound files and were presented over headphones, all measured using a sound meter to play at 95-100 decibels. One sound was a short burst of white noise, and the others were naturalistic sounds selected from the International Affective Digital Sounds (IADS) database on the basis of their high arousal and unpleasantness ratings. We employed a variety of different sounds to avoid habituation to a single repeated apprehension-inducing stimulus (e.g., white noise). Sound files were cropped to 600 ms duration to reduce context. For instance, the sound of a vehicle skidding and crashing was cropped to only the crashing sound, while the sound of an altercation was cropped to only the sound of a shriek. Trait anxiety was measured using the trait portion of the State-Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), commonly used in the study of trait anxiety and which shows high validity and reliability. Participants completed the trait anxiety questionnaire prior to completing the main experimental task.

Insert Figure 1 about here

Figure 1 (left panel) shows an example experimental trial sequence. At the start of each block, participants were asked to locate a rectangular bar that matched either a single target color (one-color search task; e.g., blue) or one of two possible target colors (two-color search task; blue or green). Each block started with a 1000 ms interval before the onset of the first trial. Every trial presented a search display for 100 ms, followed by a 1400 ms inter-trial interval which also acted as the response window. Participants located the rectangular bar that matched their target color, responding to this object's orientation by pressing the '0' or '2' key on the numeric keypad with their right index or middle finger for horizontal or vertically oriented targets, respectively. Speed and accuracy were equally emphasized. Participants completed both one- and two-color search tasks under both 'safe' and 'noise' conditions. Within safe blocks, the task was completed as described above. Within noise blocks, participants were asked to wear headphones and told that noise could be played on a small number of trials within these blocks, but that this was irrelevant to their task. Noise was played on 12.5 % of trials within these blocks, presented immediately after search display offset. Prior to the start of each safe block, participants were instructed to remove the headphones, in order to emphasize the fact that no noise would be encountered during these blocks, and to alleviate any remaining apprehension.

During practice, participants were given examples of two random sounds to ensure the volume was tolerable and that they were happy to proceed. Following this, they completed eight experimental blocks each containing 48 trials, totaling 384 trials. Safe and noise conditions were alternated on an ABAB block format, while one- and two-color search tasks were alternated following an ABBA block format. This created four possible overall block orders that were counterbalanced between participants. Each block counterbalanced target location (6), target orientation (2) and, in the case of two-color search blocks, target color. Within one-color search blocks, the choice of target color (blue or green) was randomly determined but never repeated for two successive blocks. Finally, at the end of the experiment, participants were asked to rate how anxious they felt during noise blocks, how stressed, and how generally unpleasant the noise stimuli were. Ratings were taken on a three-point Likert scale, with 1 being “not at all”, 2 being “moderately so”, and 3 being “very”.

RESULTS

Data treatment and subjective ratings

To specifically examine the role of apprehension on attentional performance, and to exclude any effects of sound-induced transient arousal, trials where noise was present were removed from analysis. In addition, as noise was presented during the interval between two search displays, the trial immediately after noise presentation was also excluded (see Gutierrez & Berggren, 2020, for similar methods). A matched number of trials were also flagged for exclusion at random within safe conditions. This was done online during data acquisition by the experimental software. For the calculation of inter-trial switch costs, data from the first trial within each block was also excluded. For RT analysis, only trials where participants responded correctly were used. For the inter-trial analyses, data was only excluded based on the response accuracy for trial N (i.e., an incorrect response on trial N-1 but correct response on trial N would be included). For analysis procedures, repeated-measures Analyses of Variance (ANOVAs) were conducted to assess within-subjects effects. To examine any influence by trait anxiety, as measured by trait anxiety scores (TAS), additional Analysis of Covariance (ANCOVA) models were run subsequently. This two-step approach was done to avoid specification error in interpreting treatment factors when covariate factors are added to a model (e.g., Engqvist, 2005). Subjective ratings showed that participants generally rated the completion of noise blocks as moderately anxiety-provoking and stressful (Meds = 2 on the three-point Likert scale), and that the noise stimuli were moderately unpleasant to hear (Med = 2).

Insert Figure 2 about here

Within-subjects effects

One-color versus two-color search tasks: Reaction times (RTs) from correct-response trials were entered into a 2x2 repeated ANOVA with the factors Task Set (One-color, Two-color) and Noise Condition (Safe, Threat). This showed a significant main effect of Task Set ($F(1,49) = 59.20$, $p < .001$, $\eta p^2 = .55$, 95% CI [.73, 1.44]), with RTs generally delayed in the two-color as compared to the one-color task ($M = 630$ vs. 575 ms; see Figure 2). There was also a significant main effect of Noise Condition ($F(1,49) = 8.26$, $p = .006$, $\eta p^2 = .14$, 95% CI [.12, .69]), with RTs generally faster in threat blocks as compared to safe blocks ($M = 598$ vs. 607 ms). However, there was no significant two-way interaction ($F < 1$), indicating RT differences between the two tasks (i.e, two-color search costs) were similar in threat and safe blocks. A matching analysis of error rate data showed a significant main effect of Task Set ($F(1,49) = 4.12$, $p = .048$, $\eta p^2 = .08$, 95% CI [.00, .57]), with a small increase in error rates during two-color as compared to one-color search (*M* = 7.12 vs. 5.87 %). There was no significant main effect of Noise Condition ($F(1,49) = 1.26$, $p = .27$; *M* = 6 vs. 7 % for safe vs. threat) and no two-way interaction ($F < 1$).

Template switch costs in the two-color task: To analyze template switch costs, performance data from the two-color search task were calculated separately for stay trials where the color target on trial N was the same as on trial N-1, and for switch trials where two different color targets were presented on trials N-1 and N. A 2x2 ANOVA with the factors Trial Type (Stay, Switch) and Noise Condition showed a significant main effect of Trial Type ($F(1,49) = 60.14$, $p < .001$, $\eta p^2 = .55$, 95% CI [.74, 1.44]) with slower RTs on switch as compared to stay trials (*M* = 651 vs. 616 ms). A main effect of Noise Condition ($F(1,49) = 4.10$, $p = .048$, $\eta p^2 = .08$) again indicated that RTs were faster within threat blocks (*M* = 627 vs. 639 ms). Crucially, there was a significant two-way interaction ($F(1,49) = 7.45$, $p = .009$, $\eta p^2 = .13$, 95% CI [.10, .67]). As can be seen in Figure 3, template switch costs were present both in safe blocks (*M* = 662 vs. 617 ms; $t(49) = 7.45$, p < .001, $dz = 1.05$, 95% CI [.70, 1.40]) and threat blocks (*M* = 639 vs. 615 ms; $t(49) = 4.18$, $p < .001$, $dz = .59$, 95% CI [.29, .89]), but these costs were strongly reduced in threat blocks (*M* diff = 24 ms, as compared to 45 ms in safe blocks). This reduction was due to the fact that RTs on switch trials were reliably faster in threat as compared to safe blocks (639 vs. 662 ms; *M* diff = 23; t(49) = 2.83, p = .007, $dz = .40$, 95% CI [.11, .69]), while there was no such RT difference between threat and safe blocks on stay trials (615 vs. 617 ms; M diff = 2; t < 1). A matching analysis of error rate data showed no significant main effects (*F*'s < 1) or two-way interaction ($F(1,49) = 1.56$, $p = .22$).

Insert Figure 3 about here

Between-subject data

One-color versus two-color search tasks: Adding Trait Anxiety Score (TAS) as a covariate factor within an ANCOVA model showed no significant main effect of TAS or any interactions on either RT or error rate data (*F*'s < 1).

Template switch costs in the two-color task: There was no significant main effect of TAS nor any interactions for RTs (*F*'s < 1.44, *p*'s > .23). For error rates, there was a marginal main effect of TAS ($F(1,48) = 3.92$, $p = .053$, $\eta p^2 = .08$), suggesting that higher trait anxiety levels were associated with generally more response errors in the two-color search task ($r = .275$). TAS did not reliably interact with either of the other two factors (*F*'s < 1.25, *p*'s > .26).

DISCUSSION

The present study examined the role of trait anxiety and induced anxious apprehension on attentional control. In contrast to previous research, which has predominantly focused on the effects of anxiety on 'tuning-out' inhibitory aspects of attention, we assessed how the ability to efficiently represent and 'tune-in' to task-relevant features in visual search may be influenced. We employed one-color and two-color visual search tasks, which required participants to maintain one or two attentional templates. In the two-color task, we also examined the costs of having to switch search templates on successive trials. Trait anxiety was assessed with a questionnaire, while an apprehensive mood was manipulated via the presence versus absence of aversive noise in different experimental blocks.

As expected, there were two-color search costs, with slower RTs in the two-color task, and template switch costs, reflected by slower RTs on switch as compared to stay trials in the two-color task, confirming previous findings (e.g., Grubert & Eimer, 2013; Houtkamp & Roelfsema, 2009; Rushworth et al., 2005). The critical question was whether and how these two types of costs would be affected by either trait anxiety or induced apprehension. There was no evidence that either of these costs was modulated by trait anxiety. This absence of such effects on the 'tuning in' functions of attentional control investigated here suggests that individual differences in trait anxious personality may only affect 'tuning out' aspects, such as distractor inhibition. In contrast, attentional control processes involved in set shifting or updating task representations in working memory may be preserved in high trait anxiety. However, such a general conclusion may not be warranted, given that the current study examined only the specific case of maintaining and coordinating attentional templates during visual search. Such templates are believed to be held in visual working memory (e.g., Olivers, Peters, Houtkamp, & Roelfsema, 2011), and to affect relatively early sensory-perceptual stages of visual processing. In contrast, the 'tuning in' aspects assumed to be influenced by trait anxiety within the Attentional Control Theory (Eysenck et al., 2007) mainly reflect higher-level executive functions. Although trait anxiety has been implicated in reducing working memory capacity (Moran, 2016), its impact on working memory mechanisms in vision has yet to be conclusively established (see Berggren, 2020; Moran, 2016, for discussion). It is also possible that effects of trait anxiety on ‘tuning in’ aspects of attention can only be found in specific task contexts. For example, Gustavson et al. (2017) found that while trait anxiety impaired the ability to switch between spatial and object discrimination tasks, this was only the case when switching away from the more difficult object discrimination task. Trait anxiety might affect performance only in attentional control tasks that have higher cognitive demands than the two-color search task employed here (see Berggren & Derakshan, 2013b, for a review of effects of cognitive load on anxiety-related differences).

In contrast to trait anxiety, apprehensive mood induced by our threat of noise manipulation had clear effects on performance. Search RTs were generally faster in threat relative to safe blocks. As sustained arousal- and affect-related aspects of induced apprehension are generally difficult to separate in studies using unpleasant sounds (see Beaurenaut et al., 2020, for discussion), this RT difference could reflect a generic increase in arousal during threat blocks, which may have expedited post-perceptual response selection and execution processes (e.g., Bocanegra & Zeelenberg, 2012). Alternatively, it may be related to attentional control, with apprehensive mood improving the ability to maintain attentional templates during search, resulting in more efficient template-guided selection of target objects. In this case, one would expect this threat-related benefit to be more pronounced during the more challenging two-color search task where two target templates had to be maintained simultaneously. We found no evidence for this, as the RT costs observed in the two-color search task relative to the one-color task did not differ between threat and safe blocks. This result indicates that, analogous to trait anxiety, current apprehension does not affect the ability to maintain multiple search templates simultaneously.

The key finding in the current study was that our threat manipulation had a strong impact on template switch costs in the two-color task. Although such costs were reliably present both in the presence and absence of threat, they were much more pronounced in safe blocks, and halved in size during threat blocks. This result is both very clear and surprising, as any impairment of attentional control by induced apprehension should have presumably resulted in an increase rather than a decrease of template switch costs. However, it is consistent with two previous studies that also found reduced switch costs under induced apprehensive mood (Kim et al., in press; Kofman et al., 2006). In the study by Kim et al. (in press), threat of mild electric shock was found to improve participants' ability to switch between color-based search strategies. Kofman et al. (2006) showed that induced apprehension facilitated switching between two simple spatial localization tasks (identifying target location as either to the left/right or above/below fixation). In these two studies, task sets were defined by simple color or location attributes. Notably, the opposite pattern (increased switch costs under heightened apprehension) was found in a task where participants switched between judging the magnitude of digits (above or below five) and their parity (odd or even; Plessow et al., 2012).

While it is possible that opposing findings in these studies may relate to other methodological factors, such as differences in the measures used to assess levels of state anxiousness or induce apprehensive mood (see Gutierrez & Berggren, 2020, for discussion), the level at which task sets were defined may be critical. In contrast to Kim et al. (in press) and Kofman et al. (2006), the task sets employed by Plessow and colleagues (2012) required the processing of more abstract semantic stimulus properties (i.e., numerical values of digits). This suggests that apprehensive mood has a dissociable impact on attentional control processes that mediate task switching, depending on the complexity of task-relevant attributes. The two-color task used in the current study was more similar to the task employed by Kim et al. (in press), as targets were defined in terms of basic visual features from the same dimension (color) in both studies. There is evidence that switching between possible target identities that are defined within the same feature dimension (e.g., two colors) influences neural activity in occipital brain regions and posterior event-related markers of attentional selection, whereas switches across feature dimensions (e.g., between color and size judgements) are associated with activation changes in higher-order fronto-posterior attentional networks and more anterior event-related markers of response selection (Becker, Grubert, & Dux, 2014). A key avenue for future research would be to contrast different types of task-switching under induced apprehensive mood, and assess whether mood can either improve or impair switching, depending on the level at which task sets are defined, and on whether shifts within or between feature dimensions are involved.

Finally, it is important to consider how induced apprehension resulted in a reduction of switch costs in the current study. Results from a recent study examining the role of apprehensive mood in task-irrelevant attentional capture (Gutierrez & Berggren, 2020) may offer some hints with respect to this question. In that study, apprehension increased distractibility, indicating that this factor impairs distractor suppression processes. A disruption to this "tuning out" function of attentional control could have paradoxically resulted in smaller switch costs during two-color search. Recent evidence has suggested that the costs observed for two-color as compared to one-color search tasks reflect inhibitory interactions between two concurrently active search templates, with the selection of a target based on one template temporarily suppressing the other template (Ort, Fahrenfort, Ten Cate, Eimer, & Olivers, 2019). If induced apprehension generally impairs inhibitory processes, including suppression between two color templates, this could have inadvertently improved target selection efficiency on switch trials during two-color search. In this case, one would expect to find complementary costs of induced apprehension on stay trials, as reduced between-template suppression should attenuate the benefits associated with repeating the same color target across successive trials. Indirect evidence for such costs were indeed present. As noted above, RTs were generally faster within threat blocks during both one-color and two-color search, which likely reflects a general alertness effect at response-related stages. However, no such RT difference was present on stay trials in the two-color task. This could be due to an RT cost associated with threat-induced reduced inhibition on these trials, which counteracted the RT benefit otherwise observed in threat blocks. It is also notable that the RT benefit observed for switch as compared to stay trials in threat blocks was twice as large as the general reduction of RTs in these blocks. This pattern of results suggests that threat reduced switch costs by attenuating both the benefits produced by target repetitions on stay trials as well the costs linked to target changes on switch trials.

In summary, the present study highlights that induced apprehension of aversive stimuli can affect ‘tuning in’ functions of attentional control in situations where multiple task templates/goals have to be coordinated. Apprehension reduced switch costs during two-color search, which may reflect a paradoxical benefit of reduced suppression between competing attentional templates. In contrast, trait differences in anxious personality did not significantly influence performance or interact with induced apprehension. This suggests either that the effects of trait anxiety are confined to ‘tuning out’ processes of attention, or to cognitive control mechanisms that operate at a higher level than those responsible for the regulation of attentional selectivity in visual perception.

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Figure captions

Figure 1: Example experimental trial display within the threat condition (not to scale). On each search display, participants were presented with six color rectangular bars. During one-color search blocks, the target was defined by a single set identity (e.g., green). During two-color search blocks, the target was defined by one of two possible colors, always blue or green. Participants responded to the target rectangular bar's horizontal or vertical orientation. Within the threat condition, at the offset of search displays, loud aversive noise was presented on 12.5% of trials. Within the safe condition, no noise was presented.

Figure 2: Mean reaction times within safe and threat conditions during one-color (light gray) and two-color (dark gray) search. Error bars denote +/- 1 SE.

Figure 3: Mean reaction times within safe and threat conditions during two-color search, shown separately for target color stay (light gray) and switch trials (dark gray). Error bars denote +/- 1 SE.

Figure 1

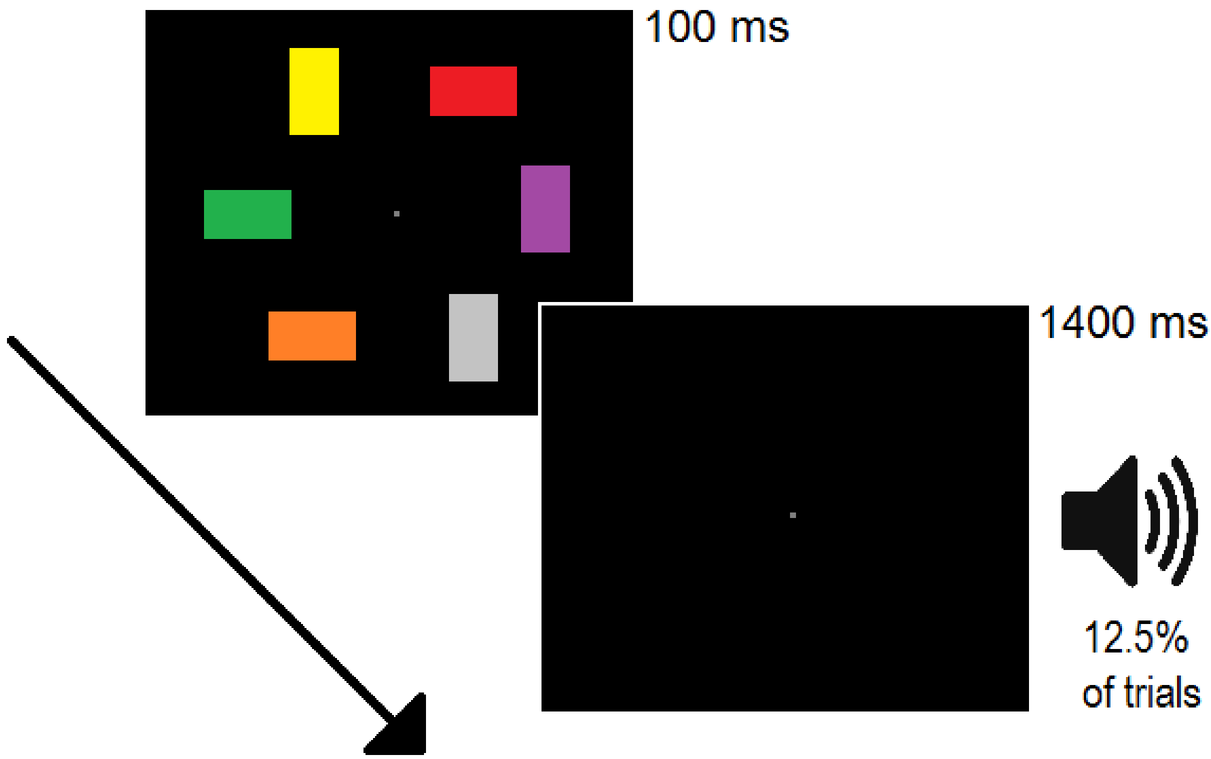


Figure 2

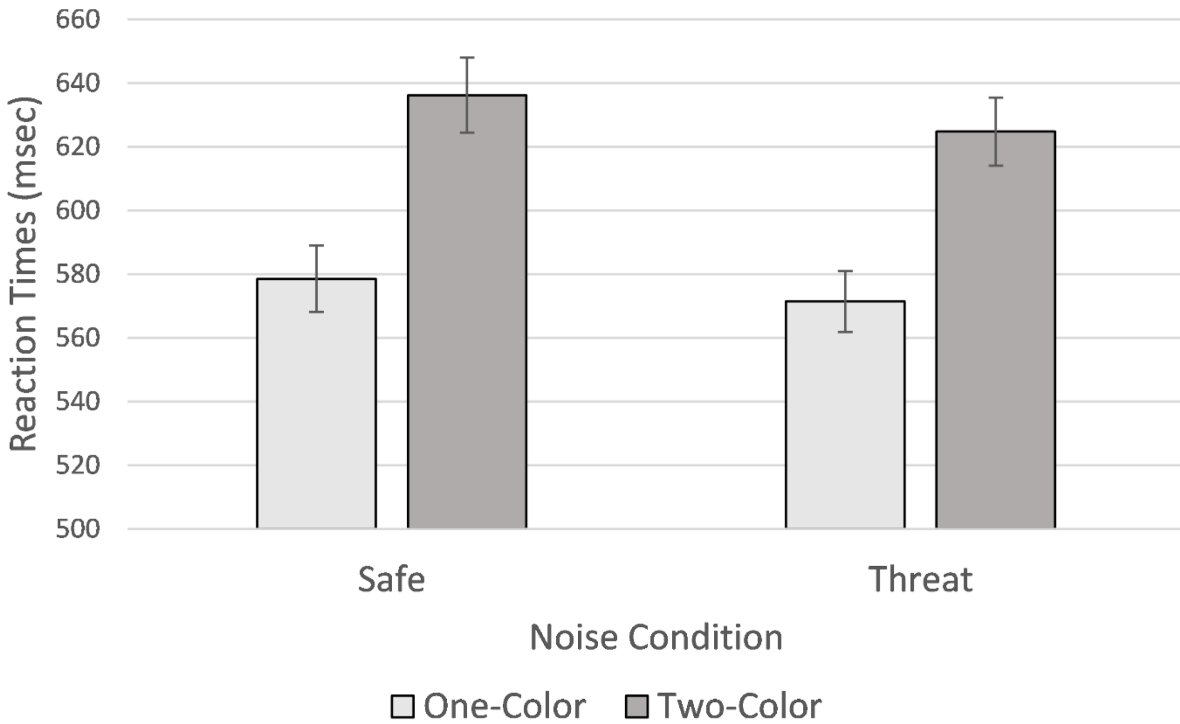
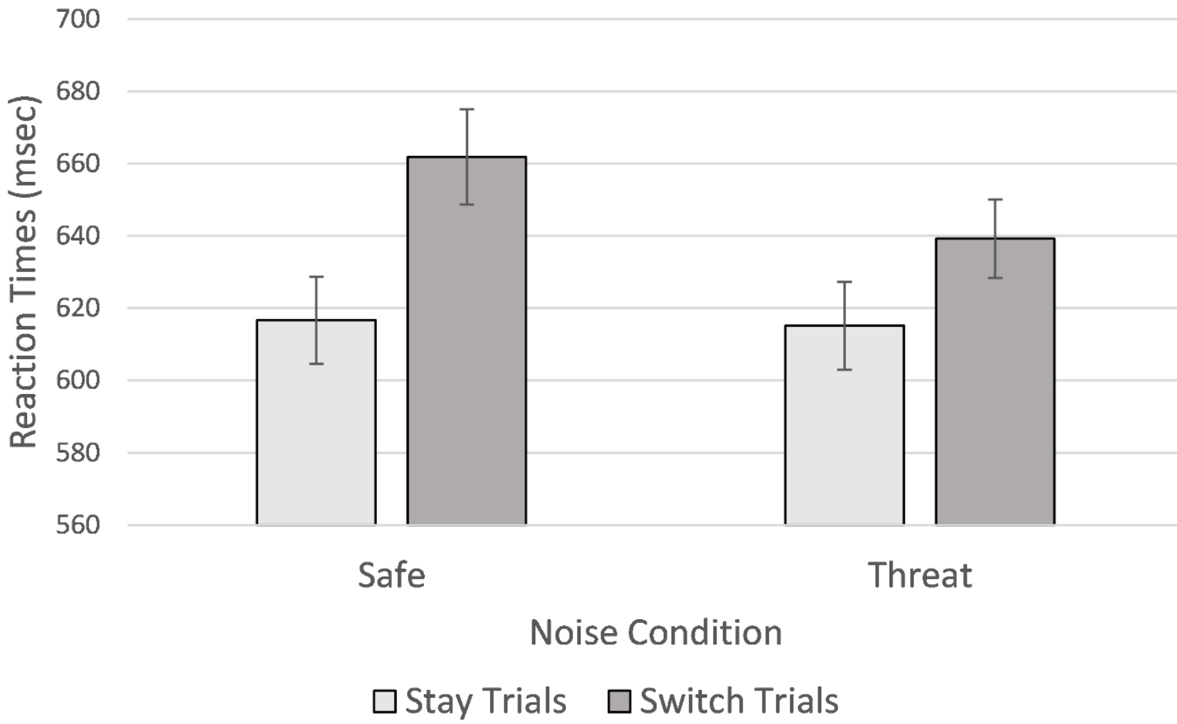

660
640
620
600
580
560
540
520
500
Reaction Times (msec)
Safe
Threat
Noise Condition
One-Color
Two-Color

Figure 3


700
680
660
640
620
600
580
560
Reaction Times (msec)
Safe
Threat
Noise Condition
Stay Trials
Switch Trials